Techno-Economic Assessment of Deep Electrification of Passenger Vehicles in India

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Contents

Introduction

- In India, there is growing interest in aggressive electrification of passenger vehicles
  - Aspirational goal of converting all vehicle sales in India to battery electric vehicles (BEVs) by 2030
  - National Mission on Electric Mobility (NMEM) with a goal of deploying 6 to 7 million hybrid and electric vehicles (EVs) by 2020
  - Given the deep reduction in battery costs in recent years, large-scale electrification of light duty vehicles seems attainable
- Key potential benefits of electric vehicles in India
  - Reduce oil import - Energy security
  - Large financial benefits to power utilities and vehicle owners
  - Lower GHG emissions
  - Potentially lower the cost of integrating renewables through "smart charging"
- Key challenges
  - Consumer confidence and uptake (cost + other barriers)
  - Impact on the power sector (capacity + distribution system)
- Given such interest and large potential benefits, designing appropriate policy, regulatory, and commercial strategies for vehicle electrification are crucial
  - Needs comprehensive assessment of the environmental and economic impacts of BEVs
  - Although these topics have been analyzed widely in the US and European context, there is very limited literature on this topic in India

Research Questions

- The objective of this study is to assess the effect of full electrification of passenger vehicle sales (i.e. cars and two-wheelers) in India by 2030 on key stakeholders such as vehicle owners, electric utilities, and the government. Specifically, we attempt to answer the following questions:
  - How does the total vehicle ownership cost of BEVs compare with the conventional vehicles?
  - What is the additional load due BEV charging?
  - What is the impact on the power sector investments, costs, and utility revenue?
  - How can smart BEV charging help renewable energy grid integration?
  - What is the impact on the crude oil imports?
  - What is the impact on the greenhouse gas (GHG) emissions?

- The key objective is to assess the key infrastructure and power availability constraints at aggressive BEV penetration
  - Assumption of 100% electrification of sales provides an upper bound on the peak load, additional revenue, and other impacts

Method, Data, and Assumptions

Methods: Using Three Models

Input Data:
Travel demand, road network, demographics, BEV and battery specifications, penetration etc.

Input Data:
Hourly load and RE profiles, power system operational constraints, investment plans, costs etc.

Plug-in Electric Vehicle Infrastructure Model (PEVI)
Agent-based model simulates the driving and charging behavior of individual drivers in a region with increasing BEV penetration

PLEXOS – Electricity Production Cost Model
Models the least cost generation and transmission investments and simulates economic dispatch for the power sector.

Economic and Environmental Impacts
Calculates (1) transport emissions and primary energy impacts, (2) benefit-cost analysis for BEV owners, utilities & power system

PEVI Output:

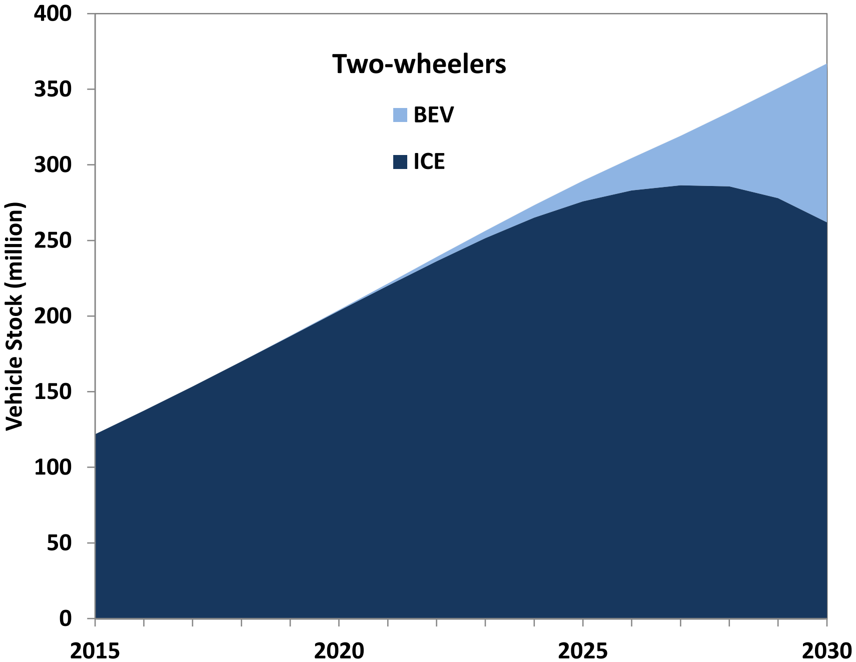
- Hourly EV charging demand, including the fraction of charging that can be shifted without impacting mobility

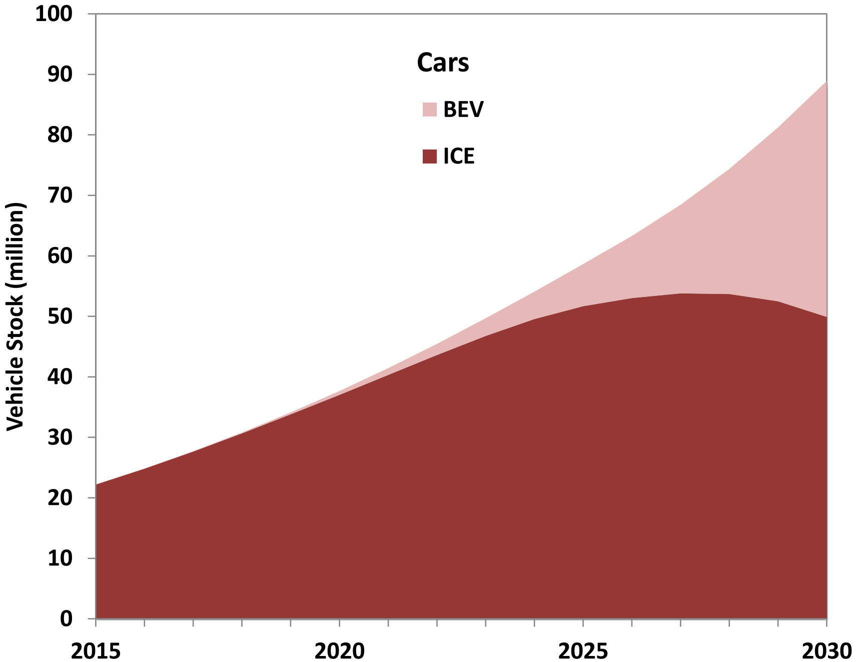
PLEXOS Output:

- New generation capacity & costs
- Hourly grid dispatch & costs
- Primary energy demand & costs
- CO_2 emissions from power plants

Vehicle Stock Projections

- We assume that by 2030, all passenger vehicle sales are BEVs
  - By 2030, BEV sales would be ~30 million two wheelers/yr and ~10 million cars/yr
- 29% of the two-wheeler stock and 44% of the car stock would be electrified (144 million BEVs total)
- If same trend continues, entire passenger vehicle stock will be electrified by 2045-2050





BEV = Battery Electric Vehicles

ICE = Internal Combustion Engine (Conventional) Vehicles

Vehicle Efficiencies and Costs

- Between 2015 and 2030, we assume that the vehicle efficiencies (ICE as well as BEV) improve and capital costs change
  - We split cars into three different classes of vehicles: subcompact hatchbacks, compact sedans, and vans/multi-use vehicles (MUVs)
  - Two-wheelers are not split into sub-classes
- For each vehicle class, we take the most popular vehicle model (by sales) in 2015 and use manufacturer labeled fuel efficiency in 2015
  - We make certain adjustments in case of BEV Sedans and MUVs since they are not widely available
- Between 2015 and 2030, efficiency improvement and cost change (as a fraction of the 2015 baseline) is taken from a study by the US National Research Council
  - We test the sensitivity of our results on the efficiency and cost assumptions

Internal Combustion Engine (ICE) Vehicles					
Vehicle Class	Model	2015 (Actual)		2030 (Projections)	
		Vehicle Efficiency (km/lit)	Capital Cost (Rs)	Vehicle Efficiency (km/lit)	Capital Cost (Rs)
Two wheelers	Honda Activa 3G	60	46,986	86	50,487
Subcompact hatchbacks	Maruti WagonR VXI	21	441,050	29	473,912
Compact Sedans	Maruti Dzire AT	19	709,598	27	762,590
Vans / MUVs	Toyota Innova	11	1,104,511	16	1,186,874

Battery Electric Vehicles (BEVs)					
Vehicle Class	Model	2015 (Actual)		2030 (Projections)	
		Vehicle Efficiency (Wh/km)	Capital Cost (Rs)	Vehicle Efficiency (Wh/km)	Capital Cost (Rs)
Two wheelers	Hero Electric Photon	32	46,150	23	38,208
Subcompact hatchbacks	Mahindra E2O Plus	114	703,905	70	582,769
Compact Sedans	-	138	1,014,725	84	840,114
Vans / MUVs	-	185	1,579,451	113	1,307,629

Electricity Grid Scenarios for 2030

- ***Business As Usual (BAU)***
  - This scenario serves as the baseline and uses the generation capacity addition for conventional technologies as projected in the Government of India's National Electricity Plan (up to 2027) extrapolated to 2030
  - For renewable energy (RE), we use projections from India's 12th Five Year Plan (up to 2022) extrapolated to 2030
  - Installed capacities by 2030:
    - Coal = 420 GW
    - Gas = 42 GW
    - Hydro, Nuclear and Other RE = 117 GW
    - Wind = 58 GW
    - Solar = 39 GW
    - Total = 677 GW
  - Non-fossil installed capacity = ~32%; RE provides ~8% energy

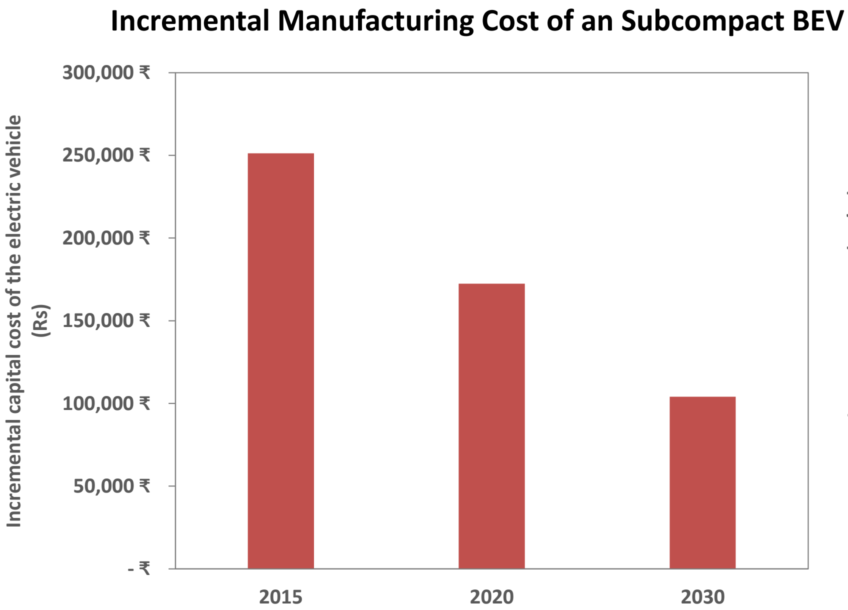
- ***Nationally Determined Contributions (NDC) Compliant***
  - This scenario models the India's recent renewable energy targets of increasing the solar PV installed capacity of to 100GW and wind installed capacity to 60 GW by 2022; we linearly extrapolate these targets to 2030
  - Coal and gas capacity expansion is "optimized" by PLEXOS; Hydro, Nuclear, and Other RE capacity assumed same as BAU
  - Installed capacities by 2030:
    - Coal = Optimized by PLEXOS
    - Gas = Optimized by PLEXOS
    - Hydro, Nuclear and Other RE = 117 GW
    - Wind = 110 GW
    - Solar = 180 GW
  - RE provides ~24% energy

- Electricity load (non-BEV) in both scenarios is take from National Electricity Plan (up to 2027) extrapolated to 2030
  - ~2,522 TWh/yr with 402 GW peak load

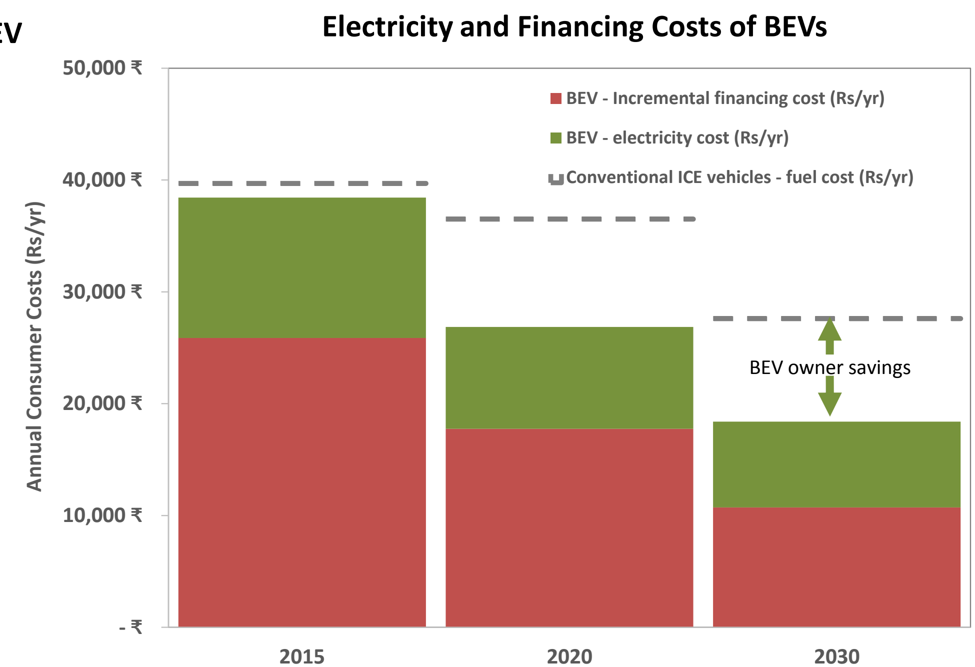
Key Results

BEV Finances and Incentive Program Design

- **Falling Battery Costs**: The cost difference between a BEV and an equivalent conventional subcompact car is expected to drop by 65% between 2015 and 2030
- **Incentive Program Design:** Fuel + financing costs of BEVs < fuel costs of conventional vehicles. BEV incentive program of loans with preferential interest rates could be successful (depends on consumer confidence in BEVs)
    - Assumptions: BEV incremental cost financed at 6% interest rate, Electricity tariff = current marginal residential tariff, ICE vehicles become more fuel efficient over time, Indian petrol price remains low and unchanged



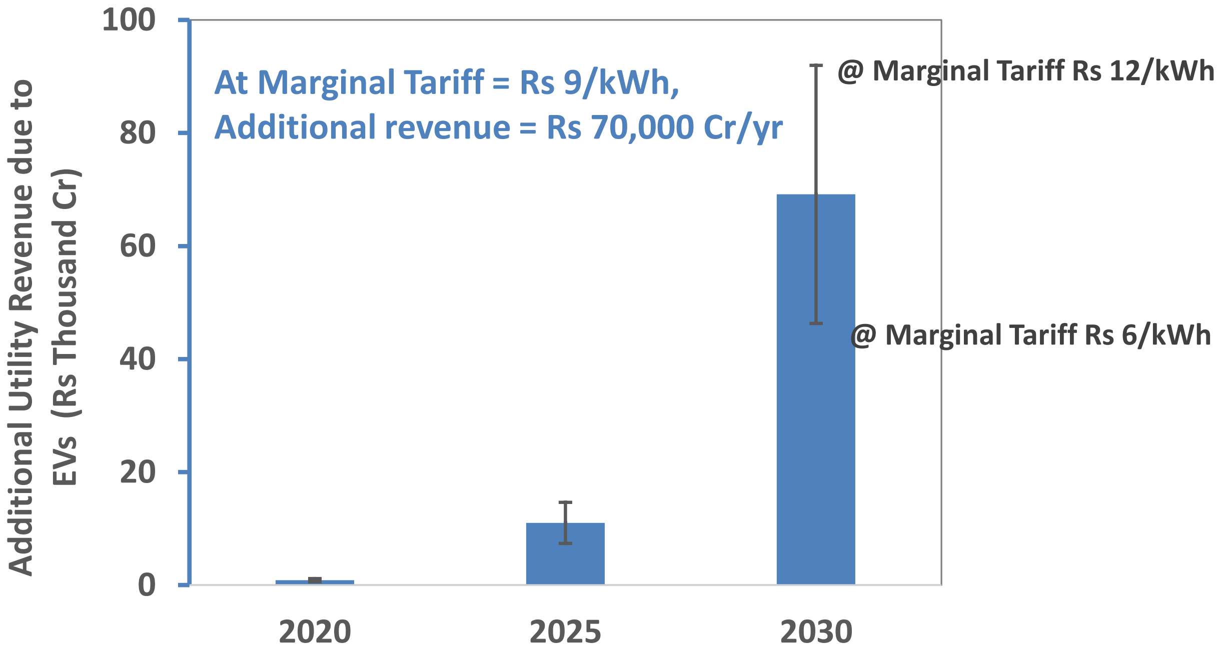
Note: These incremental costs indicate the projected difference in the manufacturing costs of BEV and ICE vehicles. These projections are highly uncertain due to rapidly evolving battery and EV technology.



Note: Gasoline price is held constant at the 2015 level (Rs 60/lit); electricity tariff is held constant at Rs 9/kWh.

Utility Financial Benefits from BEVs

- **Benefits:** Utilities can earn significant additional revenue from the new EV Charging load (~Rs 70,000 Cr/yr by 2030; additional net profit = ~Rs 25,000 Cr)
- **Challenges:** need to strengthen the distribution network, provide charging infrastructure -> could be financed by the future revenue from EV charging



- In 2014,
  - Total utility financial deficit = Rs 62,000 Cr/yr
  - Total government subsidy to utilities = Rs 36,000 Cr/yr
  - Total commercial sector revenue = Rs 42,000 Cr/yr

Power Sector Impacts of BEVs

- By 2030, additional energy requirement due to BEVs is small (82 TWh/yr, or ~3.3% of the total electrical energy demand)
- Demand growth from other end-uses such as appliances, industries, agriculture, etc will be substantially higher over the same time period
- The additional peak demand due to EV charging is ~23 GW or 5.6% of the projected peak by 2030

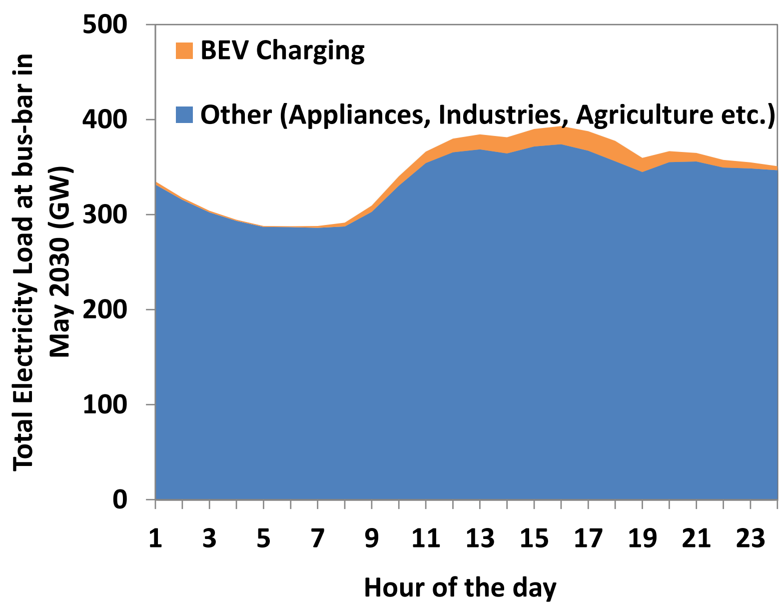
Additional energy demand from BEVs will be small

	Energy reqd per BEV in 2030 (kWh/yr)	Total BEVs in 2030 (millions)	Total Energy Reqd (bus-bar) TWh/yr*
Two-wheelers	291	105	36
Subcompact Hatchbacks	852	21	22
Compact Sedans	1030	9	11
Vans/MUVs	1381	8	14
Total		144	82

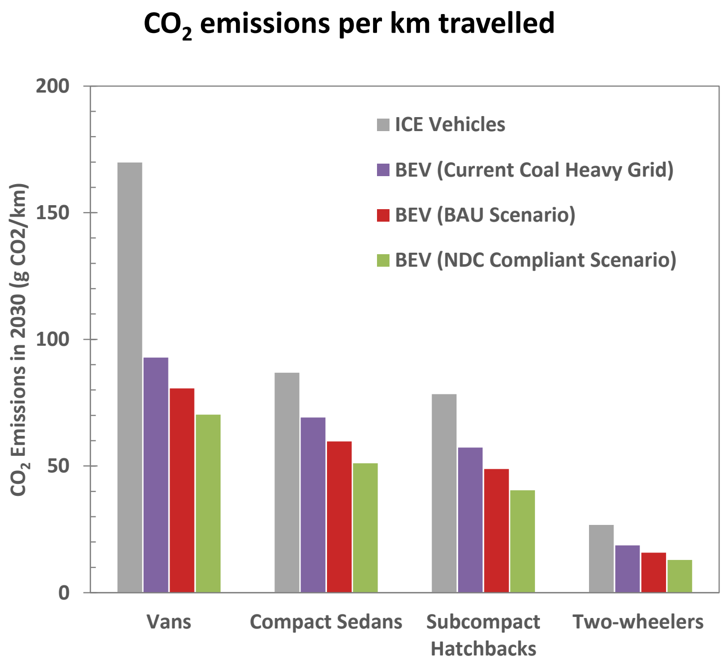
* Assuming T&D loss of 15%

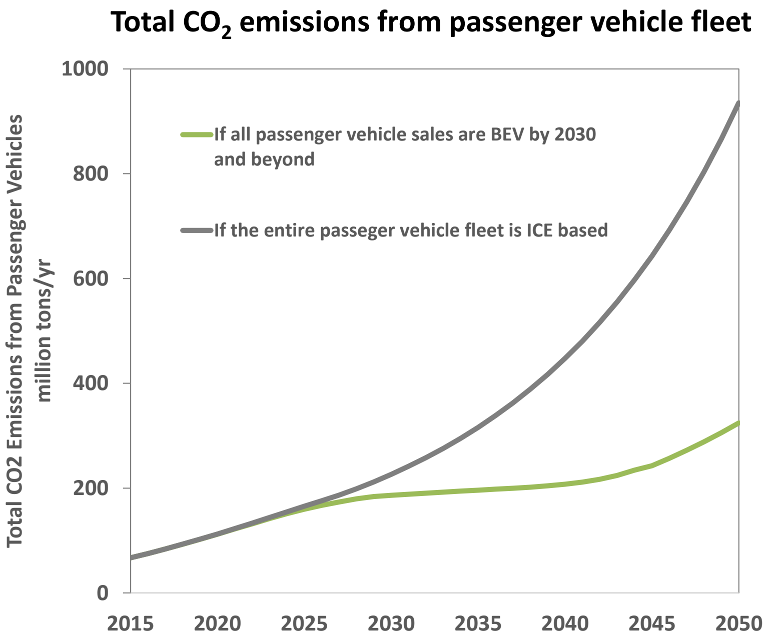
Non-BEV electricity load in 2030 (bus-bar):
Energy = ~ 2522TWh/yr
Peak = ~ 402 GW

Average daily load curve (May 2030) showing small peak demand increase



BEVs reduce GHG emissions in India – even in 2016





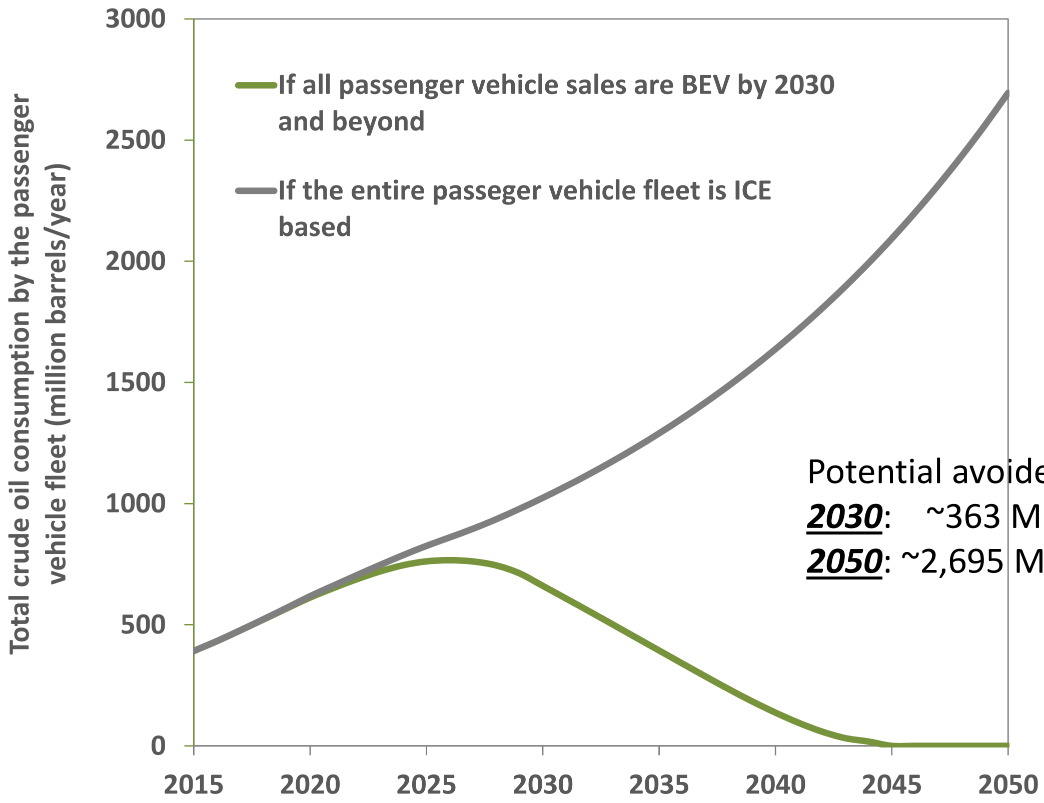
- Since BEVs are inherently more efficient than ICE vehicles, emissions reduce significantly even in the current (i.e. coal heavy) grid
- If India continues NDC RE efforts (~24% Wind + Solar in the electricity mix), passenger transport electrification alone can lower GHG emissions by ~600 million tons/yr by 2050 (8% of total GHG emissions in 2050)

➔ Much deeper decarbonization of transportation is possible with more ambitious clean power targets

BEVs will lower India’s oil import bill by $14B/yr by 2030

- Electric vehicles can reduce India’s annual crude oil import bill by $14 billion/yr by 2030 and by $100 billion/yr by 2050 (assuming a constant oil price of $40/bbl)

- By 2030, crude oil demand from the passenger vehicle fleet will peak if all vehicle sales are BEVs

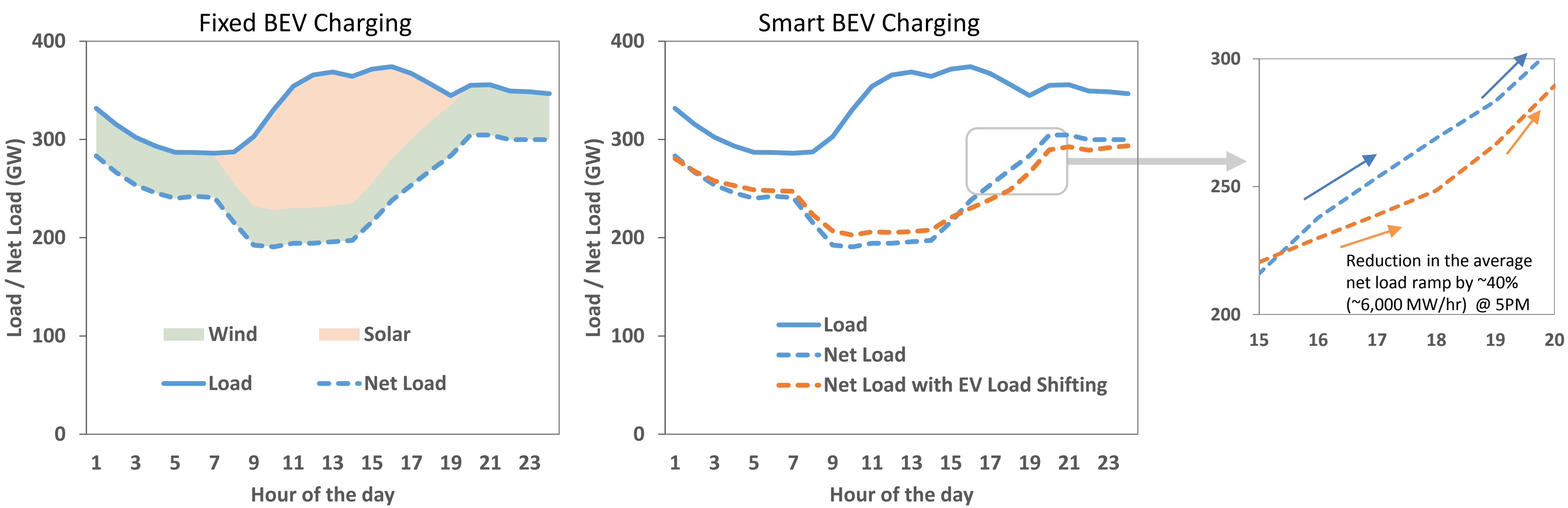


Potential avoided crude oil demand:
2030: ~363 Mbbl/yr (16% of total crude oil consumption)
2050: ~2,695 Mbbl/yr (59% of total crude oil consumption)

BEVs can provide ramping support for least cost RE integration

- The conventional generators have to meet the "net load" (difference between the load and RE generation)
- As solar generation drops near sunset, dispatchable generators need to rapidly ramp up generation to satisfy demand (aka the "duck curve" problem)
- Smart charging of BEVs can lower the cost of meeting evening ramps and therefore, the overall RE integration cost by reducing the ramping rate (MW/hr) requirement of the system
- BEVs alone could lower ramp rates by 40% on average while meeting all mobility demand

Average hourly load and net load curve for May 2030 – National (NDC compliant scenario)



Conclusions

- **Deployment Rate:** Aggressive support for BEVs must begin now to reach 100% passenger vehicle BEV sales by 2030
- **BEV Owners:** Annual fuel cost savings from switching to BEVs are greater than loan payments from financing the incremental cost of BEVs
- **Utility Benefits:** Net revenue from BEV charging alone could cut the current utility financial deficits by 50%
- **Grid Impacts:** In 2030, EV charging will only add 6% to the peak demand
- **Climate Benefits:** Passenger BEVs can reduce GHG emissions by 600 million metric tons in 2050
- **Energy Security:** BEVs can reduce India's crude oil import bill by \$14B/yr in 2030 and by \$100B/yr in 2050
- **Grid Integration of Renewables:** Smart charging of BEVs can lower the cost of integrating renewables into the Indian power grid
- **Distribution System Impacts** need to be studied in detail

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Full report can be downloaded here:

http://eetd.lbl.gov/node/62070

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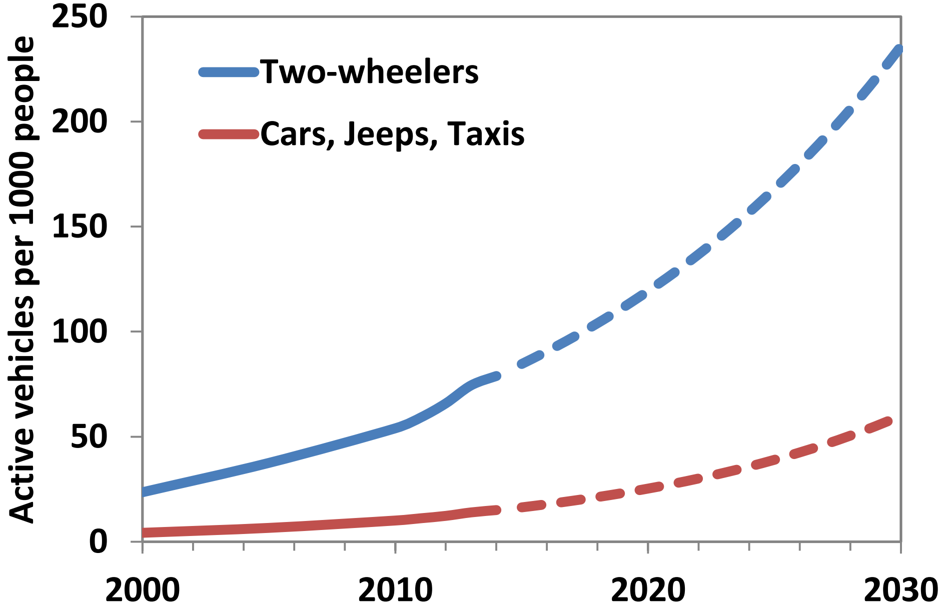
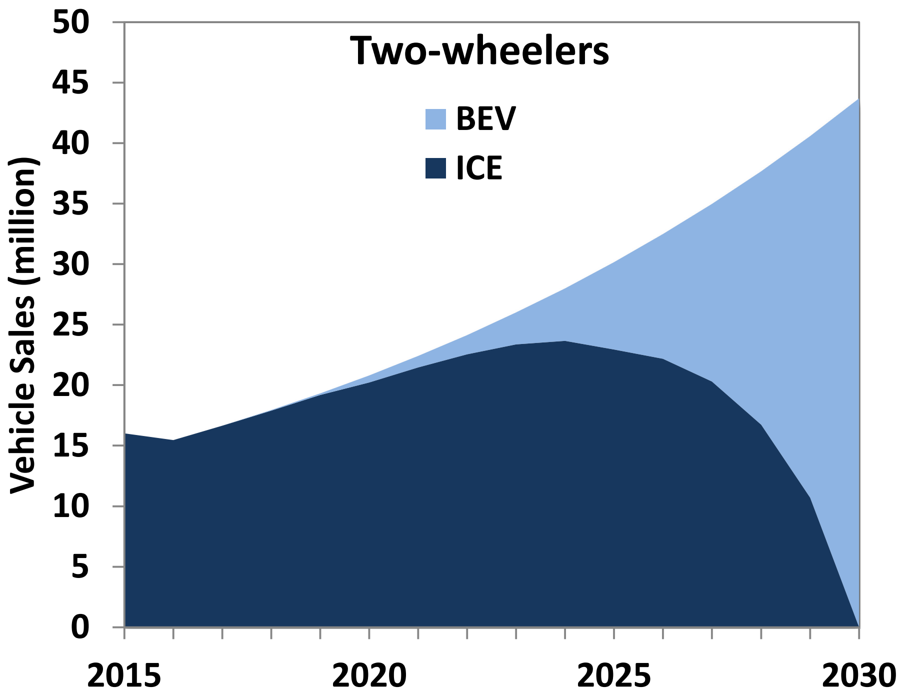
Appendix 1: Vehicle Stock and Sales

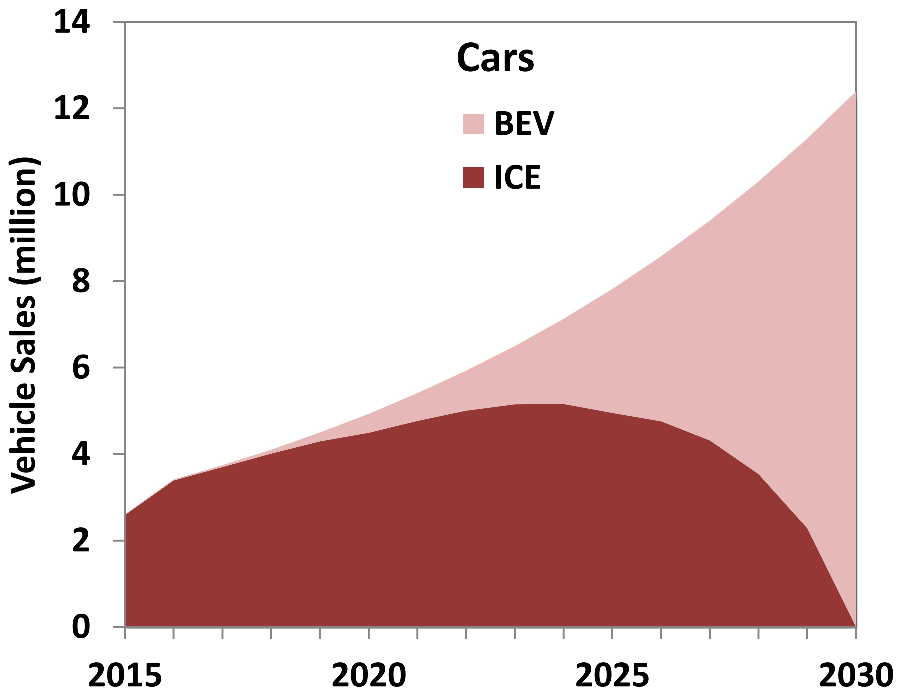
Vehicle ownership is lower than other major economies



Country	Vehicles per 1000 people (2015)
USA	809
Germany	588
Japan	588
China	54 (cars only)
India	16 (cars only)

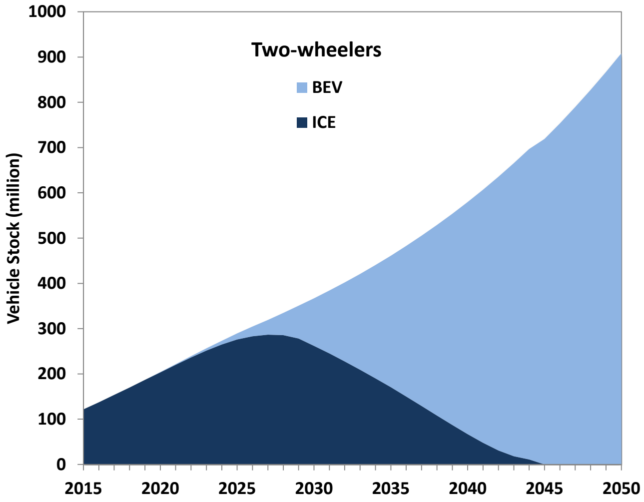
BEV sales need to grow rapidly if they have replace all ICE vehicle sales by 2030

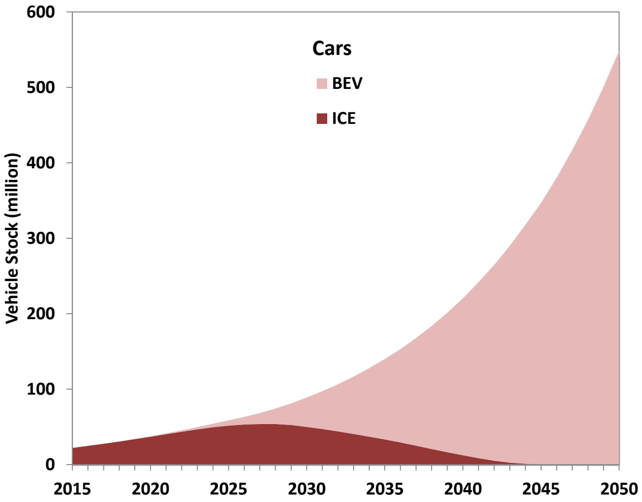


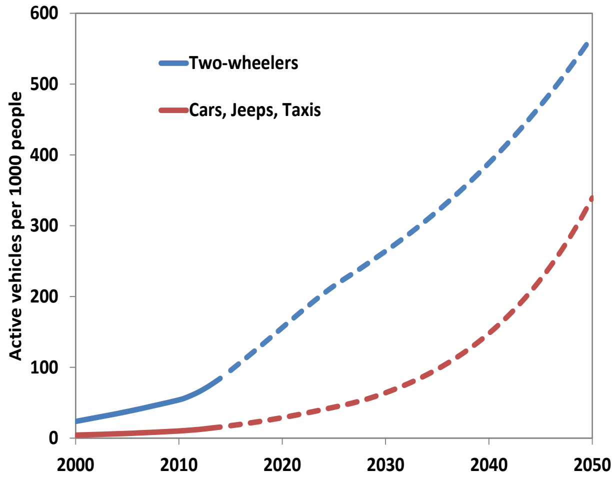


If all new vehicle sales are electric in 2030, the entire vehicle fleet is electrified by the mid-2040s

Beyond 2030, the vehicle sales growth is much faster mainly due to rising incomes and urbanization.







Country	Vehicles per 1000 people (2015)
USA	809
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Appendix 2: 2030 Grid Dispatch and Operations

To assess the value of flexible charging, we created two electricity supply scenarios

- ***Scenario 1: Business as Usual (BAU) or Baseline***
  - Installed capacities by 2030:
    - Coal = 420 GW
    - Gas = 42 GW
    - Hydro, Nuclear and Other RE = 117 GW
    - Wind = 58 GW
    - Solar = 39 GW
    - Total = 677 GW
  - Non-fossil installed capacity = ~32%; RE provides ~8% energy

- ***Scenario 2: NDC Compliant***
  - Installed capacities by 2030:
    - Coal = 361 GW
    - Gas = 42 GW
    - Hydro, Nuclear and Other RE = 117 GW
    - Wind = 110 GW
    - Solar = 180 GW
    - Total = 811 GW
  - Non-fossil installed capacity = 50%; RE provides ~24% energy

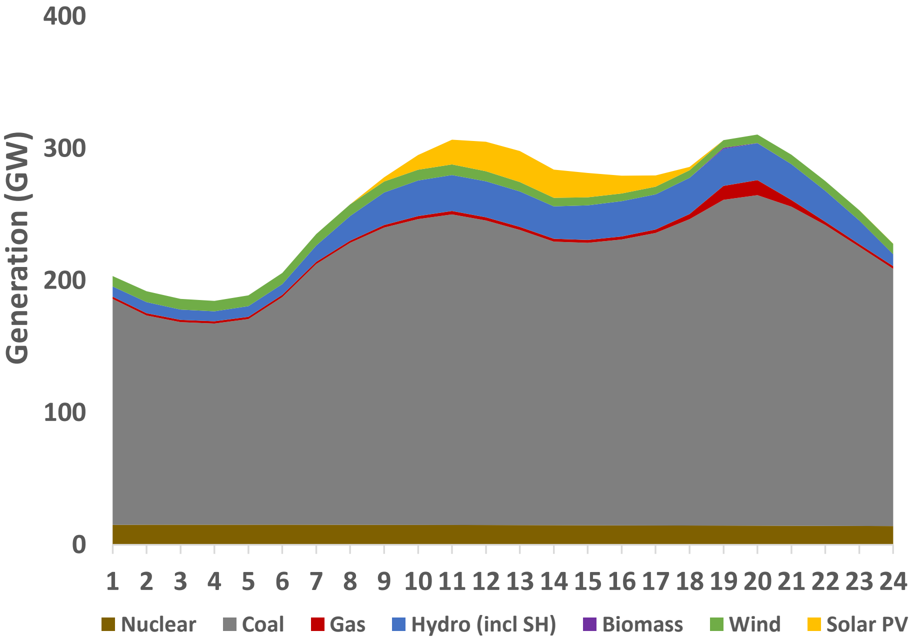
- Electricity Demand (non-BEV) in both scenarios is ~2,522 TWh/yr with 402 GW peak load

How will the system be dispatched in 2030 ? – Jan 2030

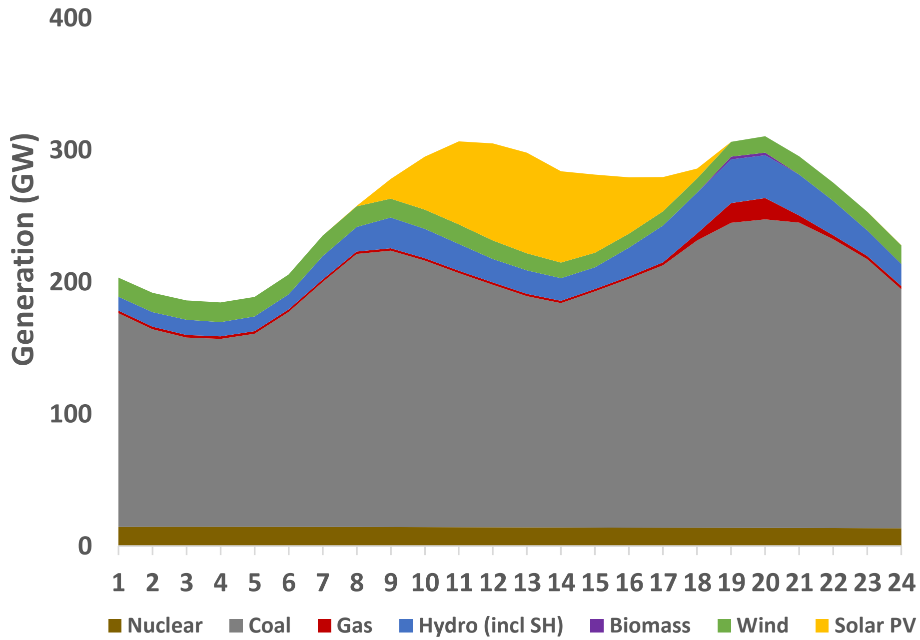
- In Winter, demand is low; but solar and especially wind generation also drop significantly.
- Significant flexible capacity (i.e. gas) is necessary to meet the evening peak.

Average hourly power plant dispatch (national) - January 2030

BAU scenario



NDC Compliant scenario

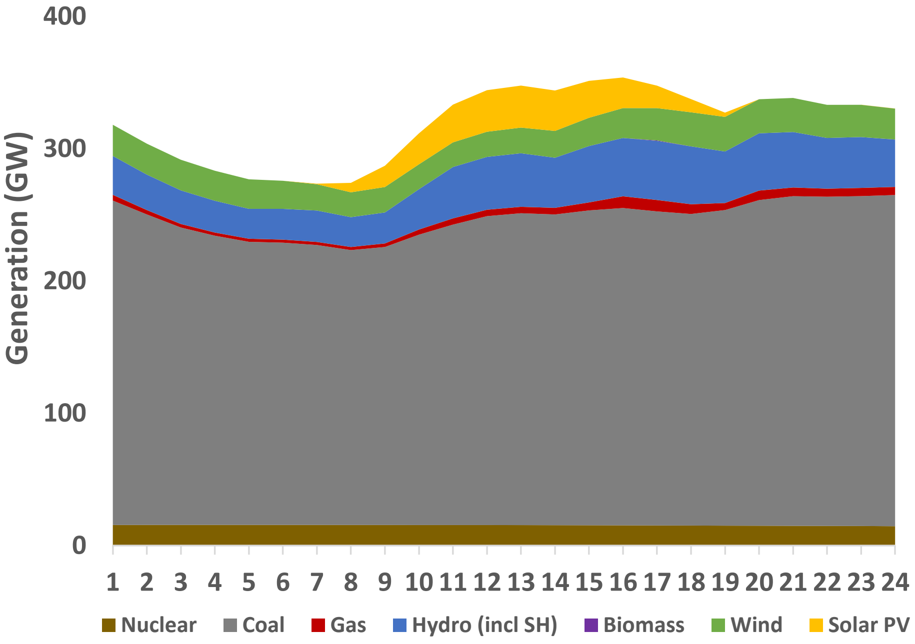


How will the system be dispatched in 2030 ? – May 2030

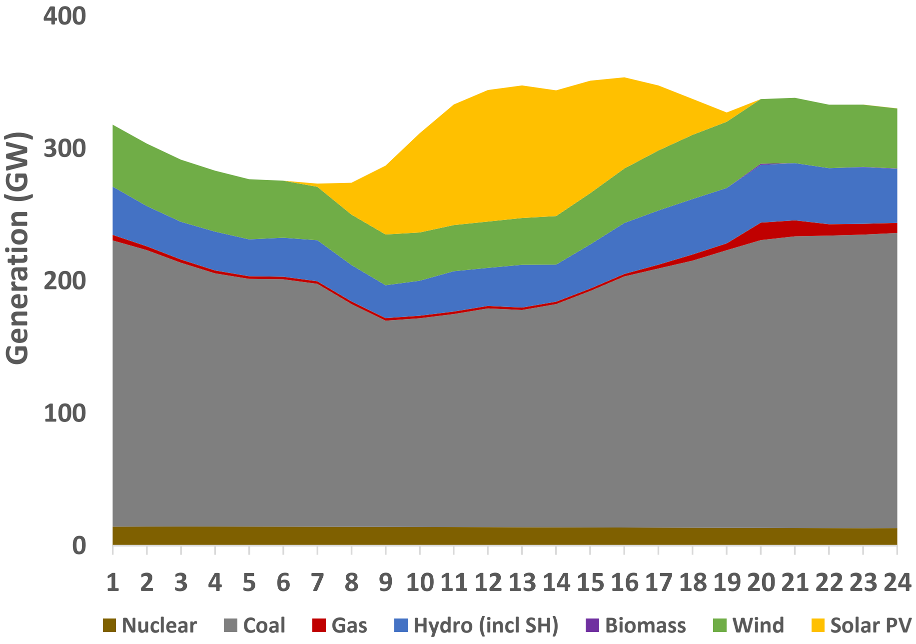
- In early summer, demand is significantly high. Wind generation is moderate while solar generation peaks.
- Solar contributed in meeting the afternoon space cooling peak.
- Some flexible (i.e. gas) capacity is required in the evening to meet the evening peak demand.

Average hourly power plant dispatch (national) – May 2030

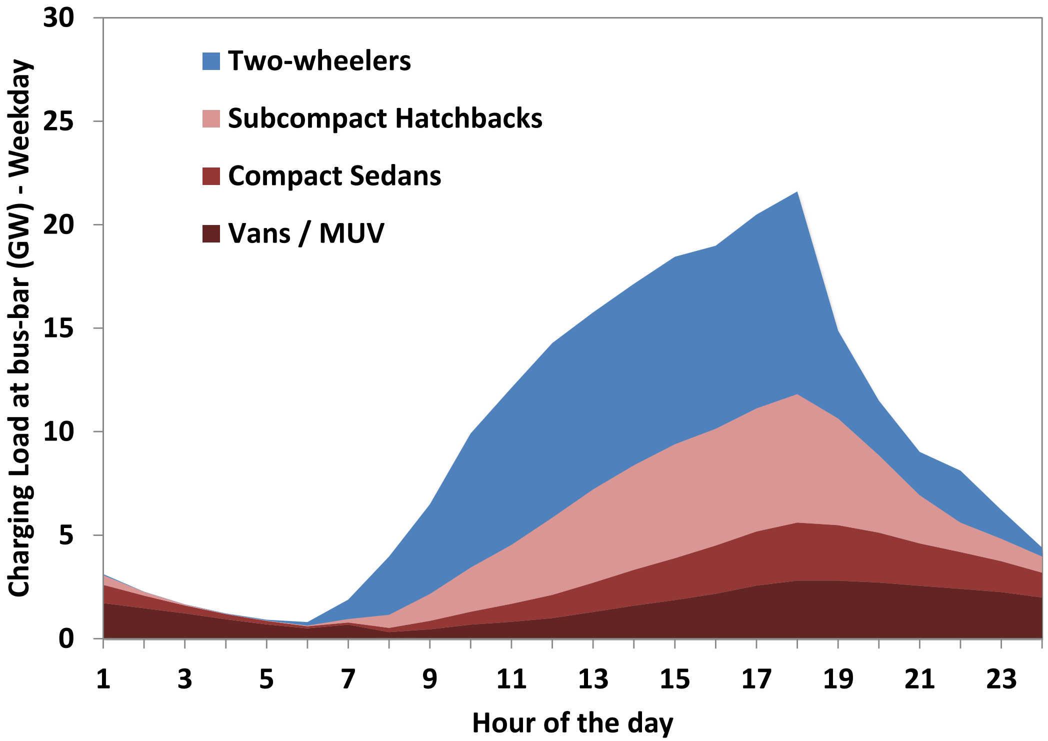
BAU scenario



NDC Compliant scenario



BEV Charging Demand (*No Smart Charging*)



- Moderate correlation with the summer peak demand (space cooling); but can introduce significant ramps on the system in the evening, especially with high solar penetration.
- If smart charging of BEVs occur:

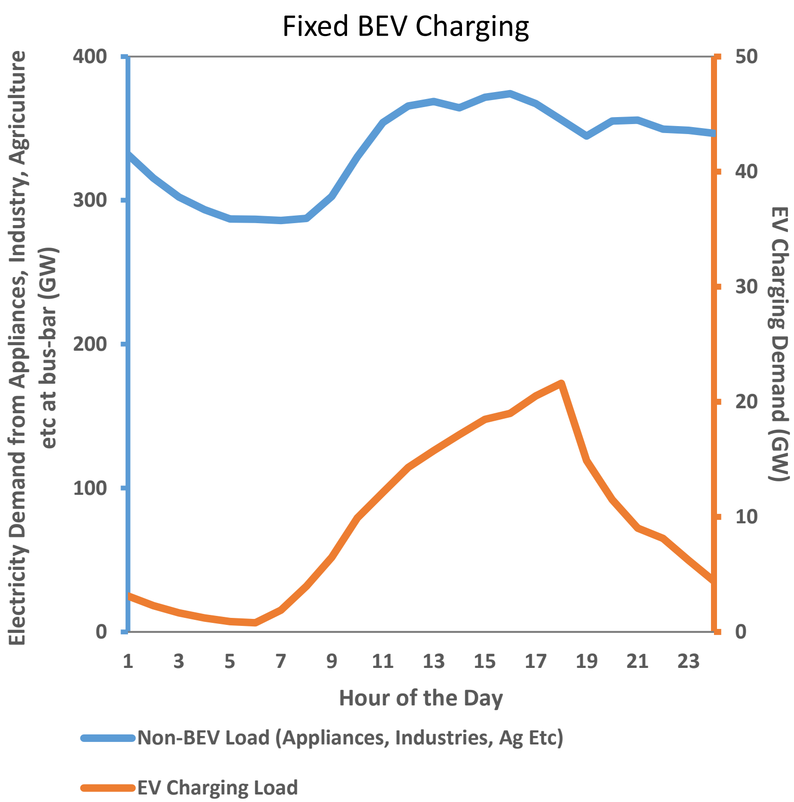
➔ Can help in managing the evening ramping requirements and system peak demand in general

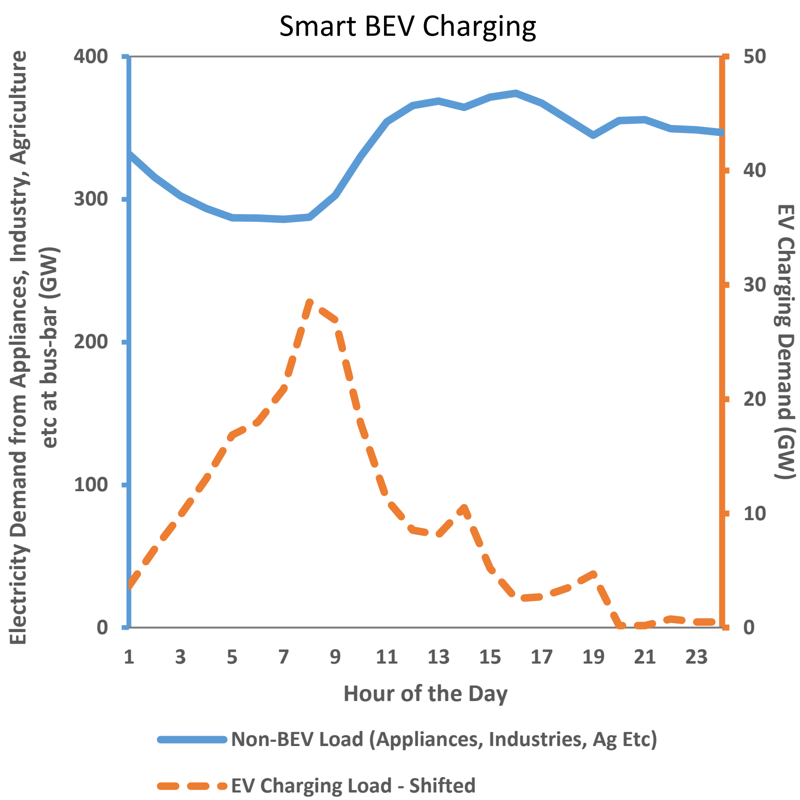
➔ Lower the cost of RE grid integration

Benefits of Smart Charging – Baseline Scenario

Most of the EV charging load could be shifted to early morning when the coal heavy system is the least constrained, **without impacting mobility demand**

Average Hourly Load (non-BEV and BEV Charging) in May 2030



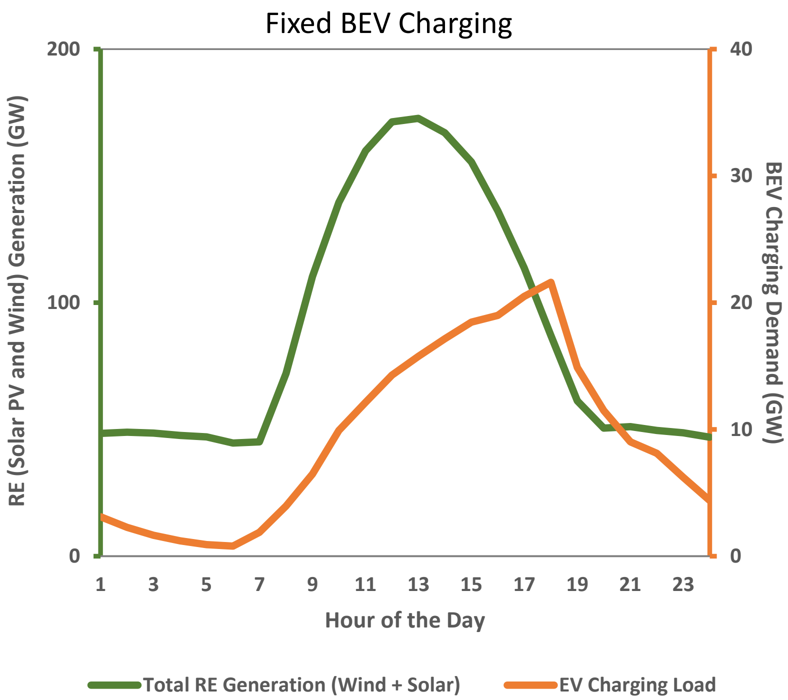


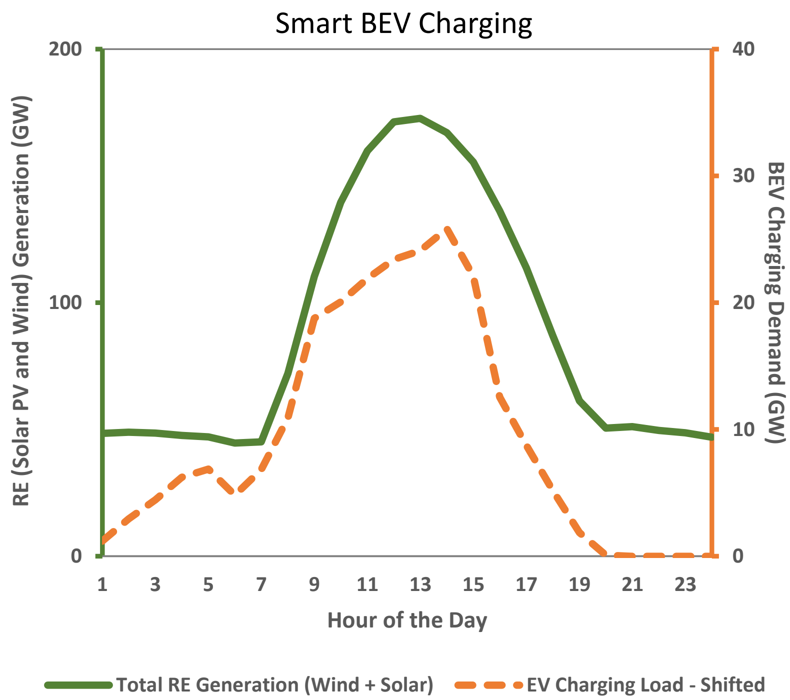
EV Charging Load shifting could reduce the average cost of generation of power by ~1% (due to better utilization factor of the generation and transmission assets)

Benefits of Smart Charging – NDC Compliant Scenario

Most of the BEV charging load could be shifted to the middle of the day **without impacting mobility demand**, to help RE grid integration; however, access to public charging infrastructure is crucial

Average Hourly RE Generation and BEV Charging Load in May 2030





BEV Charging Load Shifting could reduce the RE integration cost by ~5%